UD-FLAX PREFORMS FOR OPTIMAL NATURAL FIBRE COMPOSITES PERFORMANCE

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ABSTRACT

The negative influence of twist and crimp in flax fibre reinforced composites is already widely described. A recent development is a UD preform, in which no twist is present and of course no crimp. This UD layer is prepared without the addition of any binder. In this study UD layers of 50g/m² and 120g/m² will be processed into composites. Thermoset (RTM) as well as thermoplastic (film stacking) composites will be prepared. The processing will be optimized and the mechanical performance will be tested.

INTRODUCTION

Until a few years ago the natural fibre industry, and hence the natural fibre production was mainly oriented to the textile industry. This industry has completely different requirements than the composites industry. In this paper the consequences of this textile orientation will be explained, and some recent developments which are an answer to the new requirements will be presented.

FLAX PREFORMS

Preforms are a textile architecture in which the reinforcing fibres for a composite are put together with a specific orientation and interlacing pattern. This architecture is stabilized by the interlacing of the fibres. It is important that the fibre orientation is kept during the processing of the preform into a composite. Typical preforms are yarns, rovings, weaves, braids, ...

There is an important difference between synthetic infinite fibres and natural fibres. Natural fibres all have a limited length, because the length of their source is limited. For most of the preforms a continuous fibre form is needed. This makes it necessary to have an extra processing step with the natural fibres. During this extra processing steps the different loose fibres are processed into a continuous shape by increasing the friction between the different fibres so that they stick together. This is mostly done by applying twist on the fibres. Therefore this twist is necessary to have continuous entities, while it is negative for the mechanical properties of the composites.

Influence of twist on properties

In order to have a continuous yarn or roving the fibres are twisted. Since the increased entanglement and friction, the strength of the dry fibre bundle will increase. This increase strength makes it possible to use this continuous fibre bundle in textile techniques. However this twist is also a misorientation of the fibres, which had a direct consequence on the mechanical properties of a composite once it is impregnated[1].

There exist models [2, 3] which indicate the influence of the twist on the mechanical properties. This models use the twist angle (α) as input. The twist angle is defined as the angle that the fibres (in the fibre bundle) make at the surface with respect to the axis of the fibre bundle. Mostly the amount of twist is indicated by twists/meter. However this can be converted by

$$\tan\alpha = \frac{2\pi R}{h} \tag{1}$$

In this formula R is the radius of the yarn, while 1/h is the twists per meter[2]. In Figure 1 some results of calculations with these models can be seen. These models have been shown experimentally to predict the stiffness quite accurate, like presented in [4].

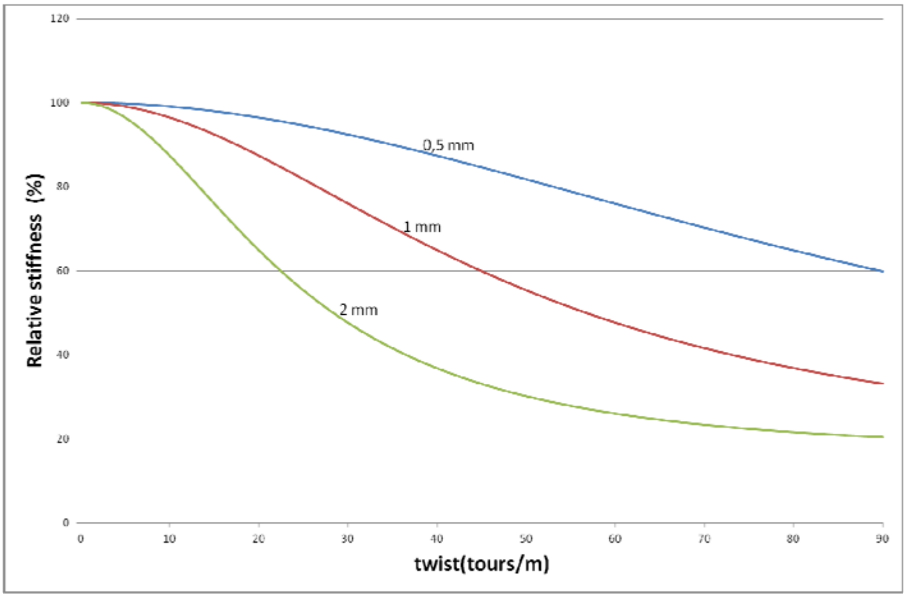


Figure 1: The relative stiffness of a UD composite with twisted yarns in function of the amount of twists and the diameter of the yarn.

Influence of crimp on properties

When yarns are interlacing each other, the yarns are also oriented out-of-plane. This is also a misorientation of the yarns or fibres and this waviness can be measured by the crimp.

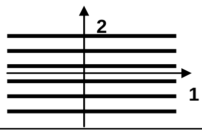
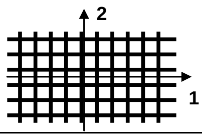
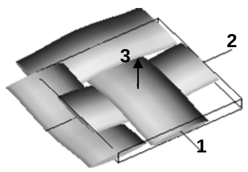
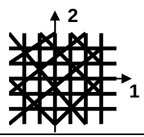
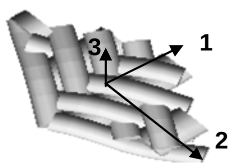
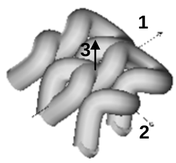
$$c = \frac{l - l_0}{l_0} \tag{2}$$

where l is the length of the yarn in the weave, l_0 is the straight distance between end points of the yarn. Crimp is connected to the inclination of the yarn, which defines the reduction of stiffness of the composite.

The influence of the crimp on the mechanical properties is dependent from the transverse properties of the fibers. Because of the strong anisotropic behavior of natural fibres, the influence of crimp is for natural fibres more negative than for glass fibers.

In Table 1, typical stiffness values of different flax textile composites are given. These values are theoretical and calculated using a model (Eshelby inclusion model), which takes into account the local orientation of the yarns. These calculated stiffness values are compared with those of UD composites, cross-ply and quasi-isotropic laminates, which do not have any crimp.

Table 1: Typical values of engineering stiffness parameters of different flax-epoxy composites with a fibre volume fraction of 60%. Fibre and matrix data used in the calculations:
Flax: longitudinal modulus 64 GPa; transverse modulus 5 GPa; Poisson coefficient 0.25
Epoxy: Young's modulus 3.0 GPa, Poisson coefficient 0.4[5]

Reinforcement	Image and coordinate system (for laminates: axis *3* is normal to the image plane)	flax/epoxy		
		E11, E22 GPa	G12, GPa	ν12
UD		39.5 4.4	2.4	0.311
Cross-ply 0/90		23 23	2.4	0.061
Plain woven, crimp 1.5%		15 15	2.2	0.023
Quasi-isotropic 0/45/-45/90		17 17	6.7	0.283
Tri-axial braid 0/60/-60, crimp braiding yarns 1%		17 15	5.8	0.267
Knitted jersey		6.5 6.0	2.7	0.301

Influence of twist on crimp

Like described above, twist has a direct negative influence on the mechanical properties. There is also an indirect negative effect of the twist. The higher the twist, the rounder the yarns will be, leading to a higher crimp when used in weaves. Because of a the negative effect of the crimp on the mechanical properties, a higher twist level leads to a negative effect on 2 levels: in-plane and out-of-plane misorientation.

Calculations to show the effect are made with the following data:

- A high twist yarn is taken, with a stiffness of 70% of the fibre stiffness and a circular section
- A low twist yarn is taken, this leads to an elliptical shape with the ratio of 1/10 for the short and long diameter, this yarn has a stiffness of 90% of the fibre stiffness [6].
- Epoxy matrix with stiffness of 3 GPa
- Fibre volume fraction is 40%

Figure 2 shows the strong impact of crimp on the stiffness. The high twisted yarns show much lower properties than the low twist yarns. Moreover, there is an additional, but smaller effect of the thickness (or tex) of the yarns: thicker yarns give slightly higher crimp and hence slightly lower stiffness. The calculations are not proven by experiments, because it is at this moment impossible to use the low twist yarns in weaves for the warp direction.

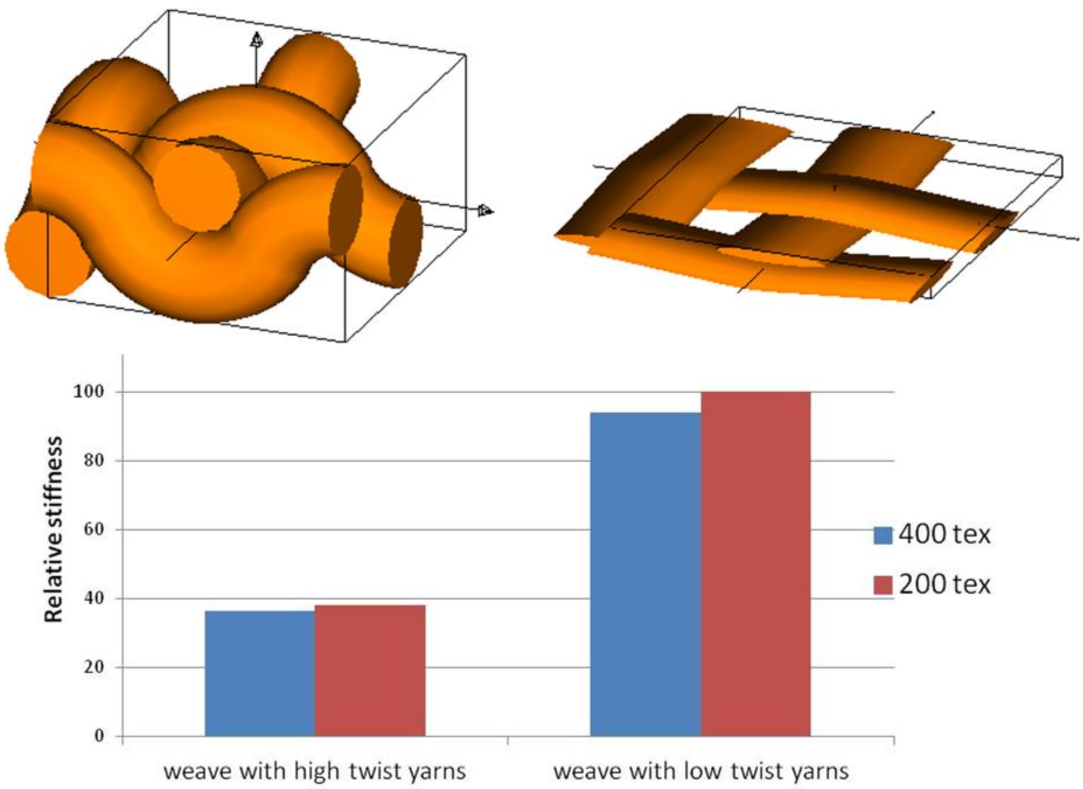


Figure 2: Relative stiffness of different weaves. The influence of the twist and the crimp is shown for yarns with 2 different linear densities. The values are relative to the value of the weave with low twist yarns of 200 tex[5].

In this paper a newly developed UD flax preform will be tested. Because of the complete absence of twist and crimp, this preform should outperform all other flax preforms currently available.

MATERIALS AND METHODS

Two flax UD layers are provided, each with a different areal weight: 50g/m² and 120g/m². The used matrix is an epoxy matrix: *Epikote 828LVEL* ($\eta \approx$ 10-12 Pa.s) combined to *Dytek DCH-99* hardener (15,2 wt%).

Different plates are produced by RTM. In the RTM process the infusion takes place at 40°C, after infusion the mould is heated to 70°C where curing takes place for 1h. After demoulding, postcuring is done in a furnace at 150°C for 1h.

It is very important to dry the flax before processing. Otherwise some bubbles occur after postcuring. Normal drying in a furnace and then transferring the flax to the mould is not enough. Because of the fineness of the UD layers it is taking up the moisture very fast. The solution is to dry the flax in the RTM-mould at 100°C under vacuum. This vacuum is kept during cooling down to 40°C for infusion.

RESULTS AND DISCUSSION

Two different types of plates are produced, UD plates and cross ply laminates. On both types tensile and 3point bending tests are performed. The results can be found in Table 2. In the results 2 stiffnesses are mentioned. The first one is calculated at the real beginning, between 0 and 0.15% strain. The second one is calculated between 0.2 and 0.4% strain. There are 2 values mentioned because it is known that there is a clear reduction in stiffness at very small deformation in flax fibre composites[7].

Table 2:Results of mechanical test on the two different UD flax preforms

		120 g/m² + epoxy		50 g/m² + epoxy	
		UD	CP	UD	CP
	Vf (%)	51	51	49	49
Tension	E (GPa) initial	34,8 ± 2,6	19,3 ± 2,0	32,0 ± 1,8	16,8 ± 1,2
	E (GPa) 0,2-0,4	26,8 ± 2,1	15,0 ± 1,5	24,0 ± 1,4	12,8 ± 0,8
	Strength (MPa)	365 ± 28	185 ± 20	382 ± 20	193 ± 13
	Failure strain (%)	1,35 ± 0,03	1,33 ± 0,02	1,57 ± 0,06	1,60 ± 0,07
Flexion	**fibre direction**				
	E (GPa)	27,5 ± 3,2	19,0 ± 1,9	26,3 ± 1,9	16,3 ± 2,4
	Strength (MPa)	294 ± 26	218 ± 9	291 ± 12	186 ± 19
	Failure strain (%)	2,6 ± 0,1	2,6 ± 0,2	2,9 ± 0,1	2,8 ± 0,2
	transverse direction				
	E (GPa)	3,26 ± 0,06	11,9 ± 0,7	3,6 ± 0,1	13,3 ± 1,7
	Strength (MPa)	34 ± 3	166 ± 6	32 ± 3	165 ± 15
	Failure strain (%)	1,12 ± 0,09	2,7 ± 0,3	0,99 ± 0,07	2,9 ± 0,1

If the fibre properties are backcalculated from the composite properties a stiffness of 69GPa is obtained and a strength of 715 MPa (neglecting the matrix properties). Which indicates that the full potential of the fibres is used in this type of preform.

Some microscopy is done to check whether the impregnation is good and the porosity limited. The pictures are shown hereunder, at left the UD and right is the cross ply. There are some porosities present they are situated around the fibres. Although it is difficult to see if it are really porosities or may be some material that is taken away during grinding and polishing.

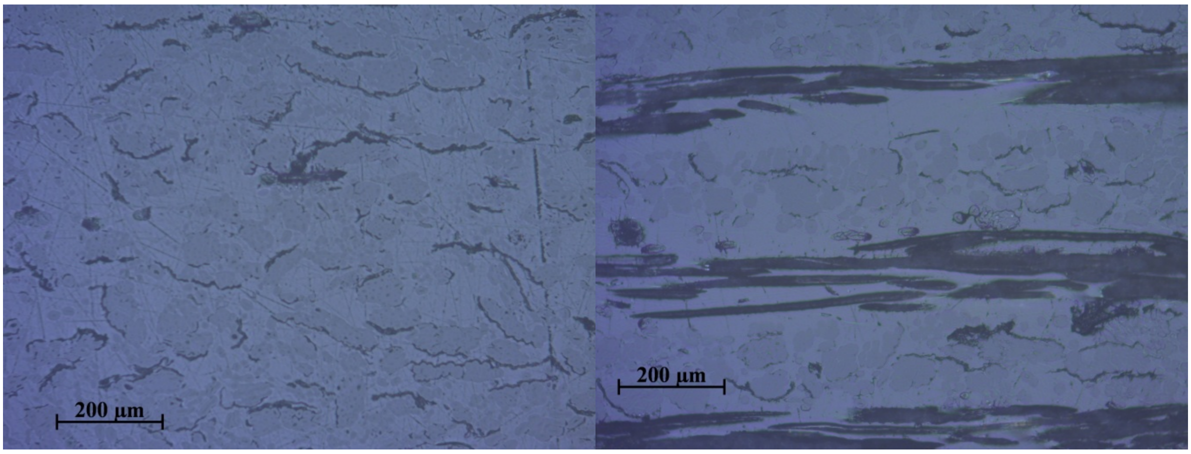


Figure 3:Microscopy pictures of epoxy composites (left) UD composite, (right) Cross-ply composite.

CONCLUSION

In the newly developed Flaxtape© the full potential of flax fibres is used. Fibre stiffness higher than 65 GPa can be obtained with a fibre strength of more than 700MPa. Another advantage of this product, is that a high fibre volume fraction is easily achievable. The disadvantage of the very fine layers is that they take up moisture very fast, which makes intense drying before production necessary.

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Twist on the Mechanical Properties of High-Performance Fiber Yarns. Journal of Applied Polymer Science. 2000;77:1938-49.

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